METHODS APPLYING COLOUR MEASUREMENT BY MEANS OF AN ELECTRONIC IMAGING DEVICE

The invention pertains to methods applying colour measurement by means of an electronic imaging device. More particularly, the invention pertains to a method of determining a colour formula for matching a selected colour measured with an electronic imaging device. The invention is also directed to a method of determining a colour formula for matching a selected colour of a textured material measured with an electronic imaging device. Finally, the invention is directed to a method for checking a selected colour measured with an electronic imaging device with a standard colour sample.

It is well-known to measure selected colours with the aid of colour meters, such as spectrophotometers and tri-stimulus meters. The measured signals may be used for the determination of a colour formula. Thus U.S. 4,813,000 discloses measuring a selected colour with the aid of a tri-stimulus colour analyser and using the measured chromaticity data to search for a colour formula in a databank. A series of articles by W. R. Cramer published in *Fahrzeug + Karosserie*, 9, 1997, 11-12, 1997, and 1-5, 1998, describes commercial applications of measuring a selected colour with the aid of a spectrophotometer and using the measured spectral data to search for a colour formula in a databank. Such methods are especially suitable for use at points of sale where paints have to be available in every colour.

It is also possible to use the measured signals to check the selected colour with a standard colour sample. Such a method is currently used in the printing inks industry.

The human eye is highly sensitive to colour differences. If a colour is to be matched, it is essential that the measurement of the colour be as accurate as possible. High measuring accuracy requires calibration. To this end there are

fixed standards defining colour in terms of standard values, so-called colorimetric data. Most common colorimetric data has been laid down by the Commision International de l'Eclairage (CIE), e.g., CIELab (L^*_{ab}, a^*, b^*), CIEXYZ (X, Y, Z), and CIELUV (L^*_{uv}, u^*, v^*). Spectral measuring data and tri-stimulus measuring data therefore have to be converted to colorimetric data if a spectrophotometer or a tri-stimulus meter is to be calibrated.

The drawback to spectrophotometers is that they are very delicate instruments. Hence a certain expertise is required on the part of the user which is not always available at the aforementioned points of sale. Moreover, spectrophotometers are expensive. A further drawback to spectrophotometers and tri-stimulus meters is that they cannot be used for measuring colour appearance including texture of the material.

The invention pertains to a method of determining a colour formula for matching a selected colour measured with an electronic imaging device, which method comprises the following steps:

a) an electronic imaging device is calibrated by measuring the colour signals of at least two calibration colours, the colorimetric data of each of the calibration colours being known;
b) at the same time or in a next step the selected colour is measured with the aid of the electronic imaging device;
c) using a mathematical model, parameters are calculated for converting the measured colour signals of the calibration colours to the known colorimetric data;
d) using the mathematical model and the calculated parameters, the colour signals of the measured selected colour are converted to colorimetric data; and
e) using a databank, the colour formula is determined of which the colorimetric data most closely matches the calculated colorimetric data of the measured selected colour.

The invention has the advantage that it is possible to make use of inexpensive consumer electronics. Consumer electronics often do not have the accurate settings required for specialist applications. The method according to the invention now makes it possible to utilise an inaccurate device for the determination of a colour formula for matching a selected colour and yet achieve a high level of measuring accuracy. In addition, the method can be performed easily by a non-specialist without him needing extensive training. The method according to the invention also makes it possible to measure a specific attribute of the colour appearance, the so-called texture.

In the method according to the invention the term "electronic imaging device" stands for all devices with which an electronic image can be recorded that can be processed with the aid of a computer. Examples of such electronic imaging devices are digital recording devices. Preferably, the electronic imaging device is a digital video camera, a digital camera, a flatbed scanner, a drum scanner, or a manually operated scanner. However, an analogue video camera coupled to a so-called frame grabber which converts the analogue signal to a digital image is also covered by the term "electronic imaging device." Finally, the term "electronic imaging device" also covers multi-spectral-imaging equipment and monochrome cameras with multiple colour filters. Examples of flatbed scanners are the Hewlett Packard 3C, Hewlett Packard Scanjet IIc, Sharp JX450, Agfa Focus Color, and Afga Arcus Plus. Examples of drum scanners are the Howtek D4000, Optronics Color Getter, and LeafScan 45. Examples of digital cameras are the Ricoh RDC 5000, Olympus C-2000Z, and Nikon Coolpix 950. Preferably, a digital camera is employed.

A minimum of two calibration colours is used, i.e. white and black. Optionally, use may be made of grey or neutral colours. For a more accurate conversion of the colour signals of the selected colour to colorimetric data preference is given to including calibration colours other than the neutral colours. The calibration colours may be selected at random. Preferably, use is made of calibration colours distributed over the entire colorimetric colour space. More preferably,

use is made of calibration colours distributed in the vicinity of the selected colour.

In theory, the physical calibration pattern can comprise as many calibration colours as may be present within the image field of the electronic imaging device. The calibration colours are recorded on the pattern in the form of patches. In theory, the calibration patches may have the size of a single pixel. In that case the size of the measuring surface will be equal to the size of the calibration patch. Depending on the electronic imaging device employed, phenomena may occur which require the calibration patch to be bigger than a single pixel. Such phenomena include stability, non-linearity, distortions, reproducibility of positioning, and cross-talk. Generally speaking, between 2 and 1000 calibration colours may be present, preferably 10-500, more preferably 25-150.

Of course, the calibration patches need not be square. Nor do they have to be rectangular or regularly shaped. There is no need to separate the colours, i.e. the colour is allowed to shift gradually.

The support on which the calibration patches are provided may be flat or curved. Preferably, the support is of uniform colour, e.g., white or grey. A clear space may be left around a portion or all of the calibration patches so as to leave the support's surface area visible. The uniform colour of the support may also serve to measure and correct any spatial non-uniformity of the electronic imaging device.

Depending on the measuring accuracy required, it may be preferred to measure the calibration colours and the selected colour simultaneously. In such cases the calibration pattern support may be provided with a recess, e.g., at the centre. Alternatively, a support may be selected which is smaller than the image field, so that the remaining image field can be used to record the selected colour.

Also, within the framework of the present invention it is possible to calibrate beforehand in step a) using a calibration pattern with more than 10 colours, then in step b) carry out a black and white calibration and measure the selected colour simultaneously. This combination of steps is useful in reducing the variation in brightness due to the influence of the light source.

Processing the recorded image, calculating the model parameters, and converting the measured colour signals to colorimetric data is all done by means of computer software. The software indicates the position of the calibration pattern and~~, optionally~~, the object to be measured. The software also includes a table listing known colorimetric data for each calibration colour and a mathematical model describing the correlation between the measured colour signals and the colorimetric data. With the aid of the software the model parameters are calculated from the mathematical model. The software then goes on to use the mathematical model and the model parameters to convert the measured signals of the selected colour to colorimetric data.

Colorimetric data may be exemplified by CIE systems such as Lab or XYZ. However, this term is not restricted to CIE systems. It may be possible to use user defined systems.

The mathematical model selected may be any model known to the skilled person. Examples are mentioned in H.R. Kang, *Color Technology for Electronic Imaging Devices*, SPIE Optical Engineering Press, 1997, chapters 3 and 11, and in U.S. 5,850,472. The model may be non-linear or linear. One example of a non-linear model is a 2nd order polynomial having 10 parameters or a 3rd order polynomial having 20 parameters. Preferably, use is made of a linear model. More preferably, the linear model used has 4 model parameters.

One example of a linear model having 4 parameters is the following model, where the measured colour signals of the calibration colours, in this case R, G, and B data, are converted to colorimetric data, in this case CIELab data:

$$L_i^* = c_0 + c_1 R_i + c_2 G_i + c_3 B_i,$$

$$a_i^*=d_0+d_1R_i+d_2G_i+d_3B_i,$$

$$b_i^*=e_0+e_1R_i+e_2G_i+e_3B_i,$$

wherein R_i, G_i, B_i, L_i^*, a_i^*, and b_i^* are the measured signals and the colorimetric data of calibration colour i.

Linear regression is used to calculate the model parameters c_0-c_3, d_0-d_3, and e_0-e_3 from the measured RGB data and the known CIELab data of the calibration colours. These model parameters are used to convert the measured RGB data of the selected colour to CIELab data.

One example of a non-linear 3rd order polynomial having 20 parameters is:

$$\begin{aligned}
L_i^* = \; & c_0 + c_1R_i + c_2G_i - c_3B_i + c_4R_i^2 + c_5G_i^2 + c_6B_i^2 - c_7R_iG_i - c_8R_iB_i + c_9G_iB_i + \\
& c_{10}R_i^3 + c_{11}G_i^3 + c_{12}B_i^3 + c_{13}R_i^2G_i + c_{14}R_i^2B_i + c_{15}G_i^2R_i + c_{16}G_i^2B_i + \\
& c_{17}B_i^2R_i + c_{18}B_i^2G_i + c_{19}R_iG_iB_i \\
a_i^* = \; & d_0 + d_1R_i + d_2G_i - d_3B_i + d_4R_i^2 + d_5G_i^2 + d_6B_i^2 - d_7R_iG_i - d_8R_iB_i + d_9G_iB_i + \\
& d_{10}R_i^3 + d_{11}G_i^3 + d_{12}B_i^3 + d_{13}R_i^2G_i + d_{14}R_i^2B_i + d_{15}G_i^2R_i + d_{16}G_i^2B_i + \\
& d_{17}B_i^2R_i + d_{18}B_i^2G_i + d_{19}R_iG_iB_i \\
b_i^* = \; & e_0 + e_1R_i + e_2G_i - e_3B_i + e_4R_i^2 + e_5G_i^2 + e_6B_i^2 - e_7R_iG_i - e_8R_iB_i + e_9G_iB_i + \\
& e_{10}R_i^3 + e_{11}G_i^3 + e_{12}B_i^3 + e_{13}R_i^2G_i + e_{14}R_i^2B_i + e_{15}G_i^2R_i + e_{16}G_i^2B_i + \\
& e_{17}B_i^2R_i + e_{18}B_i^2G_i + e_{19}R_iG_iB_i
\end{aligned}$$

Linear regression is used to calculate the model parameters c_0-c_{19}, d_0-d_{19}, and e_0-e_{19} from the measured RGB data and the known CIELab data of the calibration colours. These model parameters are used to convert the measured RGB data of the selected colour to CIELab data.

Notwithstanding the above, it is possible to lend greater weight to the calibration colours in the vicinity of the selected colour when calculating the model parameters. In the case of the above example of a linear model having 4 parameters, this means that during the linear regression each calibration colour is given a weighing factor based on the distance in the RGB colour space between the calibration colour in question and the selected colour. In the linear regression procedure the following sum of squares is minimised:

$$\sum_{i=1}^{n} w_i \left(y_i - \hat{y}_i\right)^2$$

Written out, this sum is as follows:

$$\sum_{i=1}^{n} \left(L_i^* - c_0 - c_1R_i - c_2G_i - c_3B_i\right)^2 \left((R_i - R)^2 + (G_i - G)^2 + (B_i - B)^2\right)^{-2}$$

$$\sum_{i=1}^{n} \left(a_i^* - d_0 - d_1R_i - d_2G_i - d_3B_i\right)^2 \left((R_i - R)^2 + (G_i - G)^2 + (B_i - B)^2\right)^{-2}$$

$$\sum_{i=1}^{n} \left(b_i^* - e_0 - e_1R_i - e_2G_i - e_3B_i\right)^2 \left((R_i - R)^2 + (G_i - G)^2 + (B_i - B)^2\right)^{-2}$$

wherein

n : is the number of calibration colours

R, G, B: are the measured signals of the selected colour

Alternatively, it is possible to use the calibration colours in the vicinity of the selected colour for interpolation.

If so desired, grey balancing may be performed on the signals measured for black, white, and grey according to the formula R=G=B=f(L*) or a comparable value for L* in a different colorimetric system. Such grey balancing is described in H.R. Kang, *Color Technology for Electronic Imaging Devices*, SPIE Optical Engineering Press, 1997, chapter 11. Examples of algorithms suitable for use are:

$R_{ig} = f_1 + f_2 \cdot L_{ig}^*$

$R_{ig} = f_1 + f_2 \cdot L_{ig}^* + f_3 \cdot (L_{ig}^*)^2$

$R_{ig} = f_1 + f_2 \cdot L_{ig}^* + f_3 \cdot \log(L_{ig}^*)$

wherein R_{ig} is the measured signal and L_{ig}^* is the colorimetric value of the white, grey, and black calibration colours.

Alternatively, if so desired, an offset correction of the measured data for black and white may be performed according to the following formula:

$$R_c = \left((R - R_b)/(R_w - R_b)\right) \times 255$$
$$G_c = \left((G - G_b)/(G_w - G_b)\right) \times 255$$
$$B_c = \left((B - B_b)/(B_w - B_b)\right) \times 255$$

wherein

R_c, G_c, B_c = the corrected signals for the selected colour

R, G, B = the measured signals for the selected colour

R_w, G_w, B_w = the measured signals for white

R_b, G_b, B_b = the measured signals for black

In the final step of the method according to the invention a databank is used to determine a colour formula having colorimetric data most closely matching the calculated colorimetric data of the measured selected colour. One measure of the colour difference between the colour formula and the selected colour is, e.g., the following mathematical algorithm:

$$\Delta E^*_{ab} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

wherein

ΔE^*_{ab} is the colour difference according to CIE

$\Delta L^* = L^*_1 - L^*_2$

$\Delta a^* = a_1^* - a_2^*$

$\Delta b^* = b_1^* - b_2^*$

1 = the calculated colorimetric data of the selected colour

2 = the colorimetric data of the colour formula from the databank

The smaller the colour difference ΔE_{ab}^* is, the better the match between the selected colour and the colour formula will be.

Colour formulas can be determined ~~in a~~ number of ways, i.e. by means of search procedures, calculations, or combinations of the two. For example, use may be made of a databank comprising colour formulas having colorimetric data linked thereto. Using the calculated colorimetric data of the measured selected colour, the most closely matching ~~colour~~ formula can be found. Alternatively, it is possible to use a databank having colour formulas with spectral data linked thereto. Known calculation methods can be used to calculate the colorimetric data of the colour formulas and compare them. Also, a databank can be used in which the absorption and reflection data, the so-called

K and S data, of pigments are stored. Using K and S data in combination with pigment concentrations makes it possible to calculate the colour formula of which the colorimetric data most closely match the colorimetric data of the measured selected colour. The methods in question have been described in detail in D.B. Judd et al., *Color in Business, Science and Industry*. It is possible to combine the aforesaid search and calculation methods.

Phenomena such as light source metamerism, angular metamerism, and texture will affect the colour matching.

Light source metamerism is a phenomenon where under a single light source, e.g., daylight, the observed colours of two objects may be the same visually, while under some other light source, e.g., fluorescent light, the colours differ. This can be taken into account by measuring under two light sources with different emission spectra. In the method according to the invention, advantageous use is made of an electronic imaging device, with recordings being made of the selected colour and the calibration colours under different light sources. The software needed to process different measurements of the same object is known to the skilled person.

Textured materials, such as metallic and pearlescent paints, are characterised in that the appearance of the colour changes as the angle of observation and/or exposure angle changes (angular metamerism). For proper measurement of such colours it is therefore essential to determine the colour at at least two different angles. In this process it is advantageous to make use of the method according to the invention. An electronic imaging device makes it possible to measure the colour of an object in any one of the following ways or combinations thereof:

- At least two recordings are made with the electronic imaging device while the object moves within the image field of the device ;
- At least two recordings are made with the electronic imaging device while the device moves vis-à-vis the object;

- At least two recordings are made with the electronic imaging device while a light source is moved vis-à-vis the object; or
- One recording is made with the electronic imaging device of a flat or curved section of the object when the device is able to discriminate in a single image between data at different angles.

The software required to process different measurements of the same object is known to the skilled person.

Another characteristic of materials, such as special effect paints, is texture. Texture can be defined as an arrangement of small areas having a specific colour and/or shape. It was found that by using image processing methods known as such the texture of a special effect paint can be determined from recordings made with an electronic imaging device. One way of characterising texture is by means of texture parameters. Commercially available image processing packages, e.g., "Optimas," make it possible to calculate such texture parameters using the recording. An example of such calculations is given below. Needless to say, said example should not be construed as limiting the present invention in any way.

The recording of the measured selected colour is used to determine the average brightness. Selected are areas in the recording which have much higher than average brightness. If so desired, it can be determined which areas overlap or adjoin and to separate those areas using software. Each selected area has its circumference and surface area calculated. This gives the average circumference, the average surface area, and the accompanying standard deviations for the measured selected colour. Optionally, calculations such as averaging and filtering pixels and/or pixel groups may also be included.

If so desired, the texture measurement can be calibrated by applying one or more rulers to the calibration pattern.

For matching textured materials such as special effect paint, the method according to the invention provides the possibility of linking the colour formulas

in a databank not only to colorimetric data but also to texture parameters or recordings from which texture parameters can be calculated. Using these parameters or recordings the colour formula most closely matching the selected colour also in terms of texture can be found in the databank. One example of an algorithm for finding the most closely matching colour formula which is also closest to the selected colour in terms of texture is as follows:

$$\Delta T = \sqrt{w_1 \Delta T_1^{\,2} + w_2 \Delta T_2^{\,2} + K + w_i \Delta T_i^{\,2}}$$

wherein

$w_{1\text{-}i}$ = weighing factors

$T_{1\text{-}i}$= texture parameters

It is also possible to calculate an overall parameter, e.g. ΔQ=f(ΔE, ΔT).

The method according to the invention can be applied at points of sale which have to be able to supply paint in any colour desired. A colour formula is made up of quantities of mixing colours, master paints and/or pigment pastes. Using the colour formula, the paint can be prepared in a dispenser. In the car repair sector it is customary to employ a set of mixing colours standardised for colour and colour strength. These standardised mixing colours, usually about 40 different colours, are present at the points of sale. From this set of standardised mixing colours any colour of paint desired can be made. In the DIY sector as well as the professional painting industry it is customary to use a set of master paints standardised for colour which often consists of at least one white and/or one clear master colour, i.e. a paint without pigment, optionally supplemented with master paints in a number of different colours, and pigment pastes standardised for colour and colour strength. From this set of master paints any colour desired can be made by adding pigment pastes to the master paint.

The present invention can be used with advantage in the car repair industry. In that case, the method may be carried out as follows. The colour of a car to be repaired is measured using an electronic imaging device. Prior to this or at the same time, a recording is made of a panel on which different calibration colours have been applied. The colorimetric data of the car's colour is calculated.

Software is used to generate the colour formula which after application will give a colour identical to the colour of the car to be repaired. The colour formula is prepared in a dispenser and applied.

As stated above, it may be advantageous to perform the calibration colours measurement simultaneously with the measurement of the selected colour. This is the case for instance in the car auto repair industry, where a measuring accuracy of a ΔE^*_{ab} smaller than 1 is required. In that case the method can be carried out such that in one image both a section of the car and the panel with the calibration colours are measured. The process does not require that the calibration panel is actually positioned on the car. It may be mounted somewhere else, providing it is in the same image field as the car during the recording.

Optionally, other information may be provided to be recorded with the electronic imaging device. For example, when several patterns are used, a code may be provided on every pattern. When the method of the invention is used in the car industry, information may be provided with regard to the type of car, its year of manufacturing, and other relevant information. This information may be provided in the form of bar codes, dot codes, or alpha-numerical information. A space may be provided on the calibration pattern for this kind of information. However, it is also possible to provide this information at any other place in the body shop as long as it is in the same image field as the car.

Since it has now proved possible to also measure the texture of an object with an electronic imaging device, the invention also comprises a method of determining a colour formula for matching a selected colour of textured materials such as special effect paints in which

a) the selected colour is measured with a spectrophotometer or tri-stimulus meter;
b) the texture of the selected colour is measured with an electronic imaging device; and

c) the measured colour and texture signals are used to determine, in a databank, the colour formula of which the colorimetric data and the texture parameters most closely match those of the selected colour.

It is well-known to use a spectrophotometer for measuring a selected colour of a special effect paint and use the spectral measuring data to find the colour formula most closely matching the selected colour in a databank. Such databanks often will have a texture parameter linked to the colour formula, i.e. coarseness, frequently expressed in a numerical range, such as from 0 to 10. This parameter is indicated by the user, who with the aid of swatches will determine the coarseness of the special effect paint at sight. Using a method according to the invention, it is now possible to determine the texture electronically, convert it to a coarseness value, and use this value to find a colour formula in an existing databank which most closely matches the selected colour.

Alternatively, of course, databanks can be adapted or new ones set up in which new texture parameters or recordings are linked to colour formulas.

Since special effect paints are used primarily on cars, the above methods are preferably used in the car repair industry.

Finally, the invention pertains also to a method of determining the colour difference of a selected colour measured with an electronic imaging device compared to a standard colour sample, which method comprises the following steps:

a) an electronic imaging device is calibrated by measuring the colour signals of at least two calibration colours, the colorimetric data of each of the calibration colours being known;

b) at the same time or in a next step the selected colour is measured with the aid of the electronic imaging device;

c) using a mathematical model, parameters are calculated for converting the measured colour signals of the calibration colours to the known colorimetric data;

d) using the mathematical model and the calculated parameters, the colour signals of the measured selected colour are converted to colorimetric data; and

e) the colorimetric data of the selected colour are compared to the colorimetric data of a standard colour sample.

The colorimetric data of the standard colour sample can be available in a software program. It is also possible to measure the standard colour sample before, simultaneously, or after the measurement of the selected colour. This method is preferably used in the printing inks industry.

All three methods of the present invention are not restricted to but are preferably used in the paint or printing inks industry.

The invention will be elucidated with reference to the following examples.

Examples

The measurements in these examples were performed using two different calibration patterns, both on an A4-size support. The calibration colours of the two calibration patterns first had their colorimetric data determined with the aid of spectrophotometers:

Calibration pattern 1 (see figure 1):

- 65 calibration colours distributed over the entire colour space
- The colours are from the Sikkens 3031 Color Collection

The L*, a*, and b* data of the 65 calibration colours were measured with the HunterLab UltraScan spectrophotometer with D/8 geometry. The L*, a*, and b* (daylight D65, 10°-observer) data is listed in Table 1.

Calibration pattern 2 (see figure 2):

- 37 calibration colours distributed over part of the colour space ($0<a^*<50$; $0<b^*<50$; $15<L^*<65$). The neutral colours (white/ grey/ black) are present in duplicate (colour nos. 1, 2, 6, 7, 8, 13, 14, 15, 18, and 19).
- The colours are selected from the Sikkens Car Refinishes Color Map (Autobase colours)

The 37 calibration colours were measured with different spectrophotometers, among others the Macbeth CE 730-GL, at three angles, 45/0, 45/20, and 45/-65 geometry. The spectral data was transformed mathematically to D/8 geometry. The calculated L*, a*, and b* (scanner light source of the Hewlett Packard Scanjet 5P flatbed scanner, 10°-observer) data is listed in Table 2.

Example 1

A Hewlett Packard 3C flatbed scanner was used to measure the colour of calibration pattern 1 and 149 unknown colours. The method involved each unknown colour being measured simultaneously with the calibration pattern.

The result of the measurements in other words was 149 colour images of calibration pattern 1, each time with one of the 149 unknown colours in the position of the unknown colour (see pattern 1, "unknown"). Using the linear model with 4 parameters and the weighing algorithm as described above, the colorimetric data of the 149 unknown colours was calculated.

In addition, the colorimetric data of the 149 unknown colours was measured with the aforesaid Hunterlab Ultrascan spectrophotometer with D/8 geometry (daylight D65, 10°-observer).

Table 3 presents a survey of the data. Columns 2-4 list the colorimetric data as measured with the spectrophotometer, columns 5-7 list the colorimetric data as measured using the scanner, and column 8 lists the colour differences between the spectrophotometer and the scanner colorimetric data. On average, the colour difference ΔE^*_{ab} = 2,26. The median of the colour difference ΔE^*_{ab} = 1,67. The ΔE^*_{ab}'s are also listed in Table 4.

Example 2

Example 1 was repeated, except that the measurement of the calibration pattern took place beforehand. In other words, the outcome of the measurements was one recording of calibration pattern 1 and 149 recordings of the unknown colours without calibration pattern 1.

A survey of the results is also to be found in Table 3. Columns 9-11 list the colorimetric data as determined with the scanner. Column 12 lists the colour difference between the colorimetric data determined with the spectrophotometer and those determined with the scanner. On average, the colour difference ΔE^*_{ab} = 2,23. The median of the colour difference ΔE^*_{ab} = 1,61. The ΔE^*_{ab}'s are also listed in Table 4.

Examples 3 and 4

Examples 1 and 2 were repeated, except that also grey balancing was performed using the following algorithm $R_{ig} = f_1+f_2 \cdot L_{ig}^*$. The results are listed in Table 4.

Example 5

Example 1 was repeated, except that there was no weighing. The results are listed in Table 4.

Example 6

Example 5 was repeated, except that use was made of the model with 20 parameters as described in the text. The results are listed in Table 4.

Discussion of Examples 1-6

As is clear from Table 4, Examples 1-6 show that good results can be obtained using the method according to the invention. Depending on the required accuracy, it is possible to choose among the different algorithms. It is clear from Examples 5 and 6 that a method according to the invention can be performed by simultaneously calibrating and employing a model with 4 or 20 parameters. Also, it is shown in Examples 1-2 and 3-4 that there is hardly any difference between calibrating beforehand and simultaneous calibration. This is probably the result of a combination of factors, i.e. the use of the calibration pattern with 65 colours, the mathematical model, and the Hewlett Packard 3C flatbed scanner. It is expected that a change of one or more of these factors will show better results in the simultaneous calibration than in calibrating beforehand.

Example 7

Using a Hewlett Packard Scanjet 5P flatbed scanner, the colour was measured of calibration pattern 2 and 28 unknown colours, in each case with the unknown colour being measured simultaneously with the calibration pattern. The result of the measurements thus was 28 colour images of calibration pattern 2, each time with one of the 28 unknown colours in the position of the unknown colour (see pattern 2, "unknown"). Using the linear model with 4 parameters and the

weighing algorithm as described in the text above, the colorimetric data of the 28 unknown colours was calculated.

In addition, the colorimetric data of the 28 unknown colours was calculated by measuring the colours with the aid of a MacBeth CE 730-GL spectrophotometer, at three angles, 45/0, 45/20, and 45/-65 geometry (scanner light source of the Hewlett Packard Scanjet 5P flatbed scanner, 10°-observer) and transforming the spectral data mathematically to D/8 geometry.

Table 5 presents a survey of the measuring data. Columns 2-4 list the colorimetric data as measured with the spectrophotometer, columns 5-7 list the colorimetric data as measured with the scanner, and column 8 lists the colour differences between the spectrophotometer and the scanner colorimetric data. On average, the colour difference ΔE^*_{ab} = 2,20. The median of the colour difference ΔE^*_{ab} = 2,04. The ΔE^*_{ab}'s are also listed in Table 6.

Example 8

Example 7 was repeated, except that the measurement of the calibration pattern took place beforehand. The outcome of the measurements, in other words, was one recording of calibration pattern 2 and 28 recordings of the unknown colours without calibration pattern 2.

A survey of the results is also to be found in Table 5. Columns 9-11 list the colorimetric data as determined with the scanner. Column 12 lists the colour difference between the colorimetric data determined with the spectrophotometer and those determined with the scanner. On average, the colour difference ΔE^*_{ab} = 2,24. The median of the colour difference ΔE^*_{ab} = 2,18. The ΔE^*_{ab}'s are also listed in Table 6.

Examples 9 and 10

Examples 7 and 8 were repeated, except that also grey balancing was performed using the following algorithm $R_{ig} = f_1+f_2 \cdot L_{ig}^*$. The ΔE^*_{ab}'s are listed in Table 6.

Example 11

Example 7 was repeated, except that there was no weighing. The ΔE^*_{ab}'s are listed in Table 6.

Example 12

Example 11 was repeated, except that use was made of the model with 20 parameters as described in the text. The ΔE^*_{ab}'s are listed in Table 6.

Discussion of Examples 7-12

As is clear from Table 6, Examples 7-12 show that good results can be obtained using the method according to the invention. Depending on the required accuracy, it is possible to choose among the different algorithms. It is clear from Examples 11 and 12 that a method according to the invention can be performed by simultaneously calibrating and employing a model with 4 or 20 parameters. Also, it is shown in Examples 7-8 and 9-10 that there is hardly any difference between calibrating beforehand and simultaneous calibration. This is probably the result of a combination of factors, i.e. the use of the calibration pattern with 37 colours, the mathematical model, and the Hewlett Packard Scanjet 5P flatbed scanner. It is expected that a change of one or more of these factors will show better results in the simultaneous calibration than in calibrating beforehand.

Example 13: Reproducibility

One of the 65 calibration patches of pattern 1 (no. 8) was designated as an unknown colour. The colorimetric data of the selected colour was L*=36,56; a*=56,40; and b*= 42,10.

Calibration patch 8 was measured 149 times with the Hewlett Packard 3C flatbed scanner, simultaneously with the 64 known calibration colours. The standard deviation in ΔE^*_{ab} measured over the 149 measuring points was 0,35, which is comparable with the result for a spectrophotometer.

Example 14: Reproducibility

On eof the 37 calibration patches of pattern 2 (no. 26) was designated as an unknown colour. The colorimetric data of the selected colour was L*=34,29; a*=37,55; and b*=33,64.

Calibration patch 26 was measured 28 times with the Hewlett Packard 3C flatbed colours scanner, simultaneously with the 36 known calibration patches. The standard deviation of ΔE^*_{ab} measured over the 28 measuring points was 0,17, which is of the same order of magnitude as when a spectrophotometer is used.

Table 1

Colorimetric data of calibration pattern 1 measured with the Hunterlab spectrophotometer (daylight D65, 10°-observer)

Calibration patch	Measured data (CIE)		
	L*	a*	b*
1	23,67	31,31	10,69
2	56,60	34,49	13,98
3	50,48	46,72	18,74
4	46,72	53,20	23,01
5	18,33	13,52	8,22
6	39,86	43,11	30,76
7	34,44	46,89	35,06
8	36,56	56,40	42,10
9	39,04	57,47	45,18
10	35,57	32,99	31,27
11	75,67	20,82	29,39
12	57,50	43,64	62,68
13	45,90	18,78	39,32
14	33,76	7,97	17,87
15	70,84	31,22	92,17
16	89,07	5,42	21,46
17	46,29	9,96	46,57
18	68,95	16,82	80,15
19	40,73	3,70	21,99
20	75,78	11,24	91,04
21	85,14	3,28	57,41
22	87,63	8,71	2,00
23	84,96	7,26	12,81
24	90,59	-0,42	6,25
25	89,13	1,27	1,02
26	88,89	-7,82	-1,62
27	85,73	1,84	-8,11
28	29,52	6,54	0,72
29	21,56	2,52	4,84
30	36,55	0,89	7,92
31	60,78	-3,08	6,28
32	95,23	-0,91	0,93
33	24,68	-6,48	1,02
34	80,28	-0,13	0,06
35	60,92	-0,20	0,27
36	23,45	-0,45	-0,73
37	30,50	0,26	-0,01
38	16,97	0,31	1,37
39	64,60	1,22	67,45
40	27,26	-4,14	20,17
41	54,33	-14,23	51,54

Calibration patch	Measured data (CIE)		
	L*	a*	b*
42	85,41	-14,22	26,69
43	60,75	-12,09	15,68
44	12,02	-0,39	-0,62
45	48,45	-24,08	29,04
46	27,35	-8,37	8,95
47	79,80	-12,99	14,65
48	63,89	-41,61	38,05
49	35,93	-13,81	8,00
50	40,96	-34,26	11,19
51	35,75	-38,78	0,48
52	55,84	-19,84	-5,48
53	26,09	-9,59	-5,56
54	18,92	-8,61	-8,01
55	74,36	-14,83	-15,11
56	46,17	-29,05	-25,64
57	15,61	-6,47	-10,57
58	57,39	-10,71	-17,84
59	35,59	-12,07	-29,64
60	34,45	-12,38	-37,92
61	43,42	-4,46	-22,82
62	34,21	-0,57	-34,86
63	46,34	7,69	-32,94
64	65,16	15,14	-7,60
65	43,99	22,89	-14,27

Table 2

Colorimetric data of calibration pattern 2 measured with a spectrophotometer (scanner light source of the Hewlett Packard Scanjet 5P flatbed scanner, 10°-observer)

Calibration patch	Measured data (CIE)		
	L*	a*	b*
1	17,00	-0,07	-0,34
2	26,13	-0,04	-0,20
3	59,55	6,39	43,02
4	44,03	7,81	44,48
5	40,03	8,02	27,87
6	62,52	-0,50	-0,25
7	42,18	0,09	-0,21
8	17,00	-0,07	-0,34
9	59,01	9,63	26,03
10	29,16	8,09	21,43
11	38,01	30,08	35,37
12	39,96	8,00	35,05
13	87,99	-0,35	-0,08
14	26,13	-0,04	-0,20
15	42,18	0,09	-0,21
16	57,48	20,93	39,01
17	45,24	22,82	39,82
18	62,52	-0,50	-0,25
19	87,99	-0,35	-0,08
20	28,77	21,89	23,23
21	39,85	41,15	41,44
22	39,16	25,28	24,48
23	61,21	22,30	22,38
24	59,28	42,37	39,71
25	24,05	7,78	9,13
26	34,29	37,55	33,64
27	44,14	42,56	26,06
28	54,09	42,16	25,65
29	40,45	9,54	6,44
30	58,95	8,08	7,83
31	28,76	43,21	23,63
32	22,42	24,71	9,62
33	40,61	27,92	9,67
34	25,48	39,71	9,94
35	56,69	26,87	6,45
36	43,08	40,55	4,95
37	57,23	41,44	7,64

Table 3
Measuring data of Examples 1 and 2

	Colorimetric data measured with a spectrophotometer			Simultaneous measuring and calibration				Calibration precedes measuring			
Colour	L*-ref	a*-ref	b*-ref	L*-real	a*-real	b*-real	ΔE^*_{ab} - real	L*-sing	a*-sing	b*-sing	ΔE^*_{ab} - sing
1	49,71	6,26	0,11	50,63	6,92	0,86	1,36	50,63	6,92	0,86	1,36
2	13,27	5,73	2,18	15,40	3,76	3,42	3,15	15,19	3,74	3,32	2,99
3	12,29	17,25	2,74	17,00	18,13	8,93	7,82	15,82	17,62	7,81	6,19
4	75,11	8	3,69	75,84	8,14	4,54	1,13	75,70	7,90	4,81	1,27
5	43,97	51,03	15,41	43,88	51,53	13,73	1,75	43,23	50,34	12,91	2,70
6	17,4	24,77	10,24	21,85	30,74	19,46	11,85	21,35	29,57	18,16	10,07
7	25,19	42,36	21,41	29,51	43,82	30,29	9,99	28,22	42,74	28,54	7,75
8	21,8	2,56	1,53	21,47	3,12	4,07	2,62	21,19	3,35	4,51	3,14
9	15,25	15,84	7,62	17,29	13,49	9,31	3,54	16,45	12,63	7,73	3,43
10	34,81	48,8	29,69	36,16	49,38	33,94	4,50	36,27	48,40	32,83	3,49
11	28,71	49,11	30,31	32,81	49,99	37,88	8,65	31,85	48,86	35,69	6,23
12	22,61	27,71	19,84	22,38	26,01	19,17	1,84	21,21	25,84	17,42	3,36
13	28,01	32,31	23,89	26,97	31,06	23,97	1,63	26,25	29,93	22,82	3,15
14	33,22	50,72	37	33,93	51,63	39,50	2,75	33,00	50,40	37,51	0,64
15	82,74	3,55	3,88	83,33	4,56	5,40	1,92	82,89	4,56	5,76	2,14
16	60,42	24,02	22,39	59,17	25,76	19,18	3,86	58,93	24,67	18,77	3,97
17	45,95	24,87	24,61	46,37	24,88	27,82	3,24	45,88	23,54	26,66	2,44
18	43,89	40,09	38,78	48,04	40,80	51,49	13,39	47,48	39,41	50,14	11,93
19	92,39	1,06	3,49	93,71	0,91	2,93	1,44	92,99	1,08	3,31	0,62
20	89,56	4,09	6,44	89,97	4,39	6,68	0,56	89,66	3,98	6,58	0,21
21	86,08	6,9	7,99	86,57	7,62	9,67	1,90	86,23	7,17	9,54	1,58
22	22,57	4,8	6,06	22,31	4,82	7,16	1,14	22,26	4,76	6,96	0,95
23	45,1	7,29	7,86	45,77	7,06	6,39	1,63	45,43	6,42	6,48	1,67
24	75,62	11,53	12,94	75,48	11,59	12,55	0,42	75,12	10,78	12,20	1,17
25	20,1	10,87	10,38	21,58	11,03	11,66	1,96	20,87	10,12	10,39	1,08
26	54	22,28	26,15	55,73	22,25	28,69	3,07	55,44	20,63	27,75	2,72
27	27,56	15,78	18,83	29,02	14,97	21,38	3,06	28,33	14,92	20,43	1,98
28	71,6	4,45	6,08	71,62	4,10	5,75	0,48	71,15	3,60	5,88	0,98
29	88,36	5,09	7,67	88,92	5,33	9,50	1,93	88,52	5,08	9,14	1,48
30	66,31	8,14	11,37	66,53	7,89	11,49	0,35	66,26	7,04	11,45	1,10
31	80,62	12,48	16,75	80,91	12,77	17,68	1,02	80,77	11,85	17,29	0,84
32	8,42	0,57	-0,11	13,47	-0,12	0,05	5,10	12,91	0,16	-0,24	4,51
33	52,34	2,7	5,87	53,51	2,96	6,10	1,23	53,31	2,18	6,31	1,19
34	34,61	6,16	11,87	35,29	6,25	14,68	2,89	35,26	5,53	14,81	3,08
35	27,7	13,56	22,8	29,83	13,66	24,38	2,65	29,47	13,08	23,47	1,95
36	56,51	9,55	21,34	56,69	9,46	19,03	2,32	56,61	9,41	18,95	2,40
37	25,48	1,29	4,75	24,42	1,29	5,55	1,33	24,28	0,82	6,06	1,84
38	80,87	4,88	14,71	81,05	5,35	15,48	0,92	80,71	5,04	15,45	0,77
39	64,96	8,09	23,33	65,17	8,23	22,80	0,58	65,05	7,65	22,88	0,64
40	70,72	13,31	42,15	70,81	12,61	41,30	1,10	70,78	11,54	40,89	2,17
41	51,9	18,98	54,91	53,83	18,12	62,24	7,63	53,87	17,18	62,55	8,09
42	65,68	2,34	9,17	66,02	2,31	9,82	0,73	65,89	1,95	10,19	1,11
43	52,47	2,46	9,1	52,56	2,64	7,81	1,30	52,82	1,95	8,09	1,19
44	89,61	4,12	14,61	90,63	4,20	17,04	2,63	90,35	3,87	16,42	1,98
45	84,56	7,7	26,01	84,59	7,69	26,57	0,56	84,36	7,03	25,77	0,74
46	89,79	0,81	5,19	90,27	0,74	5,92	0,87	89,78	0,97	5,96	0,79

	Colorimetric data measured with a spectrophotometer			Simultaneous measuring and calibration				Calibration precedes measuring			
Colour	L*-ref	a*-ref	b*-ref	L*-real	a*-real	b*-real	ΔE*$_{ab}$ - real	L*-sing	a*-sing	b*-sing	ΔE*$_{ab}$ - sing
47	76,67	1,44	9,09	77,02	1,49	9,27	0,40	76,42	1,33	9,33	0,36
48	45,51	1,92	9,69	46,29	2,17	8,23	1,67	45,81	1,51	8,62	1,19
49	81,64	4,39	21,07	82,05	4,51	21,75	0,80	81,61	4,15	21,33	0,35
50	81,88	1,99	11,52	82,04	1,83	11,48	0,23	81,44	1,68	11,41	0,55
51	70,97	1,77	18,31	71,40	1,77	18,76	0,62	71,19	1,20	18,94	0,87
52	80,28	2,62	20,73	80,64	2,57	21,40	0,76	80,10	2,34	21,11	0,51
53	85,34	2,93	22,93	85,92	2,59	24,07	1,32	85,68	2,11	23,30	0,97
54	65,59	5,37	49,99	66,54	5,22	55,36	5,45	66,52	4,23	55,48	5,69
55	54,62	7,61	54,69	52,93	8,17	59,01	4,67	53,21	6,95	59,06	4,64
56	70,45	1,02	42,48	71,84	1,05	43,87	1,97	71,84	0,07	43,51	1,98
57	89,88	0,18	9,66	90,55	-0,04	10,52	1,11	90,15	0,15	10,16	0,57
58	88,51	0,77	13,07	89,11	0,70	14,58	1,63	88,63	0,59	13,95	0,91
59	77,02	-0,37	14,1	77,40	-0,19	14,30	0,46	76,71	-0,51	14,13	0,34
60	46,16	-0,62	20,09	46,11	-0,19	19,42	0,80	45,81	-0,92	19,70	0,60
61	78,14	-1,25	30,03	79,29	-1,13	31,39	1,78	78,76	-1,52	30,90	1,10
62	92,66	-0,15	8,14	94,21	-0,12	8,50	1,59	93,93	0,12	8,62	1,38
63	85,33	-0,16	10,42	85,99	-0,05	11,57	1,33	85,65	-0,12	11,68	1,30
64	66,7	-1,31	11,69	66,72	-1,12	12,70	1,03	66,81	-1,49	13,05	1,37
65	55,97	-1,72	9,92	56,88	-1,59	9,68	0,95	56,67	-2,35	10,19	0,98
66	45,98	-6,41	28,68	45,07	-5,61	27,82	1,48	45,32	-6,51	29,05	0,77
67	87,22	-1,25	4,43	87,59	-1,36	4,86	0,58	87,10	-1,28	4,92	0,51
68	52,72	-1,9	5,23	53,73	-1,43	5,22	1,11	53,32	-2,10	5,69	0,78
69	71,08	-1,71	5,96	71,36	-1,46	5,91	0,38	70,86	-1,95	6,30	0,47
70	30,92	-2,65	8,69	30,90	-3,12	9,87	1,27	30,76	-3,57	9,93	1,55
71	35,23	-7,34	28,35	36,88	-8,86	30,92	3,41	36,96	-9,49	31,81	4,42
72	55,65	-5,3	9,65	56,01	-5,30	8,96	0,78	55,73	-5,89	9,53	0,61
73	66,67	-5,66	9,97	66,01	-5,67	10,96	1,19	66,06	-6,09	11,48	1,68
74	75,32	-6,33	11,78	74,95	-5,62	10,93	1,17	74,20	-5,61	11,10	1,49
75	85,09	-7,32	12,63	85,21	-7,00	12,84	0,40	84,45	-6,65	13,03	1,01
76	35,1	-7,84	15,88	34,77	-9,59	16,72	1,97	34,65	-10,40	17,03	2,84
77	83,16	-4,27	6,37	84,00	-4,35	7,25	1,22	83,26	-4,15	7,53	1,17
78	57,75	-4,28	6,42	58,14	-3,93	6,13	0,60	57,86	-4,41	6,64	0,28
79	43,77	-2,11	2,4	44,83	-0,79	2,25	1,70	43,86	-1,77	2,16	0,43
80	62,94	-17,03	21,53	62,46	-17,78	18,89	2,78	61,96	-18,20	19,95	2,20
81	92,95	-1,12	1,25	95,73	-0,68	1,26	2,82	94,11	-0,53	1,94	1,47
82	85,51	-10,69	10,42	86,08	-10,21	11,20	1,07	85,06	-9,66	11,58	1,62
83	71,5	-13,48	12,33	70,53	-13,50	10,96	1,68	69,83	-13,62	11,40	1,92
84	48,62	-15,07	12,12	48,97	-13,92	8,73	3,59	48,42	-14,40	9,43	2,78
85	40,29	-19,75	15,51	39,53	-21,46	16,39	2,07	39,63	-21,59	17,19	2,58
86	36,69	-31,82	23,66	36,32	-36,81	23,26	5,02	36,05	-36,72	24,58	5,03
87	46,08	-2,07	1	47,04	-1,10	0,13	1,61	46,37	-1,81	0,36	0,75
88	92,14	-4,27	3,62	93,42	-3,80	3,86	1,38	92,36	-3,44	3,99	0,93
89	64,1	-9,61	6,11	63,08	-9,95	6,58	1,17	62,78	-10,46	6,86	1,74
90	77,38	-11,04	7,27	76,38	-9,96	6,19	1,83	76,10	-9,60	6,46	2,09
91	84,65	-13,66	8,73	84,28	-13,15	8,43	0,70	84,55	-13,32	8,46	0,44
92	20,03	-13,51	6,95	21,05	-10,84	6,42	2,91	20,82	-11,13	6,60	2,53
93	16,47	-5,88	3,55	17,88	-4,26	3,74	2,15	17,66	-4,44	3,93	1,91
94	80,15	-7,24	3,29	80,35	-6,80	3,18	0,50	80,13	-6,37	3,79	1,01
95	25,92	-26,75	8,14	27,34	-23,30	10,41	4,37	26,58	-23,45	11,21	4,56
96	24,78	-20,28	10,67	26,14	-18,20	11,50	2,62	25,83	-18,15	12,42	2,95

	Colorimetric data measured with a spectrophotometer			Simultaneous measuring and calibration				Calibration precedes measuring			
Colour	L*-ref	a*-ref	b*-ref	L*-real	a*-real	b*-real	ΔE^*_{ab} - real	L*-sing	a*-sing	b*-sing	ΔE^*_{ab} - sing
97	19,87	-17,69	1,36	20,96	-13,31	2,93	4,78	20,71	-13,05	3,23	5,07
98	34,47	-1,78	0,06	33,29	-1,45	0,53	1,31	33,10	-1,85	0,77	1,54
99	66,95	-11,78	0,9	67,00	-11,22	0,70	0,59	67,06	-11,41	1,24	0,52
100	84,68	-14,11	0,5	85,61	-13,50	1,06	1,25	85,17	-12,97	1,53	1,61
101	15,57	-8,82	1,1	17,33	-5,54	1,67	3,77	17,38	-5,57	2,50	3,97
102	66,63	-21,42	1,1	65,80	-20,16	-0,44	2,16	65,70	-20,45	0,43	1,51
103	74,69	-24,05	0,99	73,40	-22,97	-0,51	2,26	73,02	-22,85	0,50	2,11
104	50,57	-8,52	-1,31	51,47	-6,93	-1,28	1,83	50,98	-7,34	-0,79	1,35
105	24,96	-21,45	-3,88	25,48	-17,88	-1,52	4,31	24,87	-18,89	-0,99	3,86
106	89,5	-8	-0,03	89,91	-7,90	0,01	0,43	89,04	-7,27	0,00	0,87
107	78,28	-6,99	-1,42	78,87	-6,57	-1,69	0,77	78,20	-6,55	-0,97	0,63
108	76,27	-9,39	-2,48	76,98	-8,66	-1,88	1,18	76,08	-8,35	-1,24	1,63
109	41,82	-33,66	-10,54	41,30	-34,95	-15,13	4,80	40,07	-35,25	-14,15	4,32
110	13,47	-3,55	-0,46	15,67	-2,50	-0,14	2,45	15,25	-2,69	-0,48	1,98
111	85,64	-11,02	-3,87	86,78	-11,24	-3,27	1,30	85,78	-10,67	-3,05	0,90
112	55,62	-16,3	-9,34	56,25	-16,42	-9,66	0,72	55,42	-16,73	-8,92	0,64
113	74,41	-19,23	-10,85	74,67	-19,05	-11,26	0,52	73,42	-18,53	-9,76	1,63
114	44,63	-22,33	-12,21	44,27	-23,85	-15,99	4,09	43,38	-23,86	-15,08	3,48
115	64,98	-25,34	-13,59	64,98	-26,00	-14,58	1,19	63,82	-25,84	-13,82	1,28
116	35,8	-25,91	-12,3	37,26	-25,02	-13,64	2,17	35,97	-25,34	-13,44	1,29
117	55,08	-30,07	-18,19	54,22	-32,22	-22,17	4,60	53,28	-32,28	-21,52	4,38
118	84,46	-1,29	0,51	85,21	-1,61	0,87	0,89	84,70	-1,62	1,22	0,82
119	84,05	-8,05	-5,37	84,60	-8,71	-5,55	0,88	83,77	-8,19	-5,10	0,42
120	17,55	-9,69	-8,14	18,39	-8,54	-7,96	1,44	17,26	-8,41	-7,75	1,37
121	75,09	-14,85	-13,41	74,99	-15,49	-14,48	1,25	73,82	-14,81	-13,16	1,30
122	46,22	-16,7	-16,15	46,43	-17,10	-18,57	2,46	45,59	-17,31	-17,69	1,77
123	34,65	-22,41	-17,08	37,28	-21,03	-16,94	2,98	36,13	-21,50	-16,92	1,74
124	35,92	-2,36	-3,28	36,05	-2,35	-5,74	2,47	35,22	-2,54	-5,29	2,13
125	33,28	-7,89	-10,48	33,52	-6,94	-12,78	2,50	31,28	-7,47	-13,03	3,27
126	60,78	-2,18	-2,34	62,32	-2,80	-2,12	1,68	61,92	-2,89	-1,74	1,47
127	88,07	-4,84	-4,32	88,82	-5,48	-4,00	1,04	87,95	-5,08	-3,57	0,80
128	77,27	-5,51	-7,67	77,82	-5,57	-7,50	0,58	76,85	-5,35	-6,89	0,90
129	26,12	-7,6	-10,42	23,03	-7,40	-12,16	3,55	22,22	-7,67	-12,14	4,27
130	46,5	-12,86	-19,97	47,01	-13,83	-22,37	2,64	45,41	-14,44	-22,36	3,06
131	34,35	-15,69	-23,64	36,29	-14,40	-22,56	2,57	35,46	-14,67	-22,27	2,04
132	13,95	-6,52	-9,95	14,34	-5,43	-10,92	1,51	12,95	-4,52	-10,88	2,42
133	29,14	-9,05	-17,19	29,02	-7,27	-19,85	3,20	27,22	-7,78	-20,49	4,02
134	38,61	-16,21	-32,23	39,68	-17,01	-31,73	1,43	38,18	-16,19	-31,46	0,88
135	35,55	-2,44	-8,44	35,85	-2,32	-10,06	1,65	34,53	-2,78	-9,99	1,88
136	30,16	-4,21	-17,49	30,07	-2,97	-19,91	2,72	28,56	-4,03	-20,03	3,00
137	28,41	-10,54	-27,45	29,13	-7,90	-28,72	3,02	27,12	-8,05	-29,60	3,53
138	17,22	-4,06	-20,74	16,25	-4,69	-21,22	1,26	13,12	-5,09	-23,93	5,30
139	63,15	0,23	-0,42	64,10	-0,21	-0,36	1,04	63,94	-0,66	0,18	1,33
140	45,11	0,22	-10,33	46,60	1,61	-9,72	2,13	45,52	0,76	-9,37	1,17
141	24,07	-1,35	-28,46	24,11	-0,98	-30,36	1,94	22,17	-1,52	-31,40	3,50
142	18,96	2,37	-24,13	18,40	0,42	-26,24	2,93	16,61	0,15	-27,22	4,47
143	14,08	0,48	-13,51	13,38	-2,65	-16,50	4,38	12,16	-2,60	-17,19	5,17
144	7,52	0,26	-0,42	13,17	-0,51	-0,46	5,70	12,29	0,43	-0,80	4,79
145	72,89	4,49	-16,85	73,42	4,24	-16,65	0,62	72,85	3,80	-16,07	1,04
146	25,46	8,16	-39,29	23,04	8,45	-42,90	4,36	21,25	8,06	-43,78	6,16

	Colorimetric data measured with a spectrophotometer			Simultaneous measuring and calibration				Calibration precedes measuring			
Colour	L*-ref	a*-ref	b*-ref	L*-real	a*-real	b*-real	ΔE^*_{ab} - real	L*-sing	a*-sing	b*-sing	ΔE^*_{ab} - sing
147	13,54	0,94	-0,58	15,28	0,05	0,39	2,18	14,44	0,17	-1,20	1,34
148	33,21	19,83	-12,82	31,61	22,05	-13,55	2,83	30,37	21,19	-14,86	3,75
149	44,52	25,98	-6,76	44,01	26,20	-7,24	0,73	42,96	24,19	-8,56	2,98

Table 4
Average and median of ΔE_{ab} of Examples 1-6

	Number of model parameters	Weighing	Calibration beforehand	Simulta-neous calibration	Grey balancing	ΔE_{ab} average	ΔE_{ab} median
1	4	Y	----	Y	-----	2,26	1,67
2	4	Y	Y	-----	-----	2,23	1,61
3	4	Y	----	Y	Y	2,21	1,60
4	4	Y	Y	-----	Y	2,15	1,56
5	4	-----	----	Y	-----	2,91	2,15
6	20	-----	----	Y	-----	2,32	1,74

Table 6
Average and median of ΔE_{ab} of Examples 7-12

	Number of model parameters	Weighing	Calibration beforehand	Simultaneous calibration	Grey balancing	ΔE_{ab} average	ΔE_{ab} median
7	4	Y	----	Y	----	2,20	2,04
8	4	Y	Y	----	----	2,24	2,18
9	4	Y	----	Y	Y	2,59	2,40
10	4	Y	Y	----	Y	2,55	2,25
11	4	----	----	Y	----	3,12	3,22
12	20	----	----	Y	----	4,44	2,72

Table 5
Measuring data of Examples 7 and 8

	Colorimetric data measured with a spectrophotometer			Simultaneous measuring and calibration				Calibration precedes measuring			
Colour	L*-ref	a*-ref	b*-ref	L*-real	a*-real	b*-real	ΔE^*_{ab}-real	L*-sing	a*-sing	b*-sing	ΔE^*_{ab}-sing
1	34,21	16,65	16,48	34,23	14,77	19,33	1,60	34,23	14,77	19,33	1,60
2	33,18	15,57	23,9	34,04	14,44	24,83	2,03	34,03	14,53	24,77	2,10
3	35,72	17,79	33,24	34,39	14,77	31,50	2,35	34,38	14,77	31,43	2,41
4	32,08	21,48	17,81	31,48	19,18	20,39	1,72	31,61	19,49	20,44	1,67
5	37,03	23,94	32,59	38,29	20,06	33,84	0,31	38,34	20,24	33,99	0,46
6	33,59	33,8	18,02	31,05	29,59	16,98	5,16	30,93	30,41	17,07	4,95
7	33,58	32,06	24,65	33,61	28,99	26,61	1,26	33,76	29,18	27,19	1,08
8	34,29	37,55	33,64	35,96	35,04	36,93	1,62	35,97	35,19	37,25	1,94
9	45,51	17,17	16,13	45,80	15,32	17,25	0,60	45,80	15,44	17,13	0,57
10	50,32	14,45	24,96	51,21	9,16	26,71	2,45	51,40	9,57	26,90	2,31
11	48,99	16,91	36,51	50,31	9,76	38,19	2,75	50,38	9,80	38,15	2,71
12	50,54	25,58	16,78	52,81	22,78	19,78	2,39	52,72	22,71	19,85	2,41
13	52,96	22,31	32,5	54,30	16,16	35,87	2,05	54,36	16,21	36,05	2,16
14	45,62	32,24	17,62	45,13	28,98	18,54	2,46	45,22	29,10	18,45	2,39
15	50,63	34,07	24,3	51,79	28,81	27,34	2,90	51,95	29,53	27,21	2,21
16	51,8	37,11	36,22	53,99	32,45	41,31	2,55	54,22	33,08	41,63	2,96
17	18,88	15,9	9,19	20,03	13,39	9,41	1,28	20,14	13,72	9,38	1,16
18	29,15	20,6	24,53	29,32	17,30	27,26	1,81	29,89	17,61	27,27	1,46
19	18,05	-5,02	-15,56	15,18	-1,07	-16,41	4,63	15,16	-0,97	-16,55	4,53
20	31,51	51,33	31,58	31,74	45,45	29,20	3,13	31,55	46,96	29,31	3,76
21	26,8	24,49	19,3	26,48	23,43	21,15	1,75	26,51	23,84	21,86	2,32
22	44,94	32,01	44,81	48,16	27,24	47,26	1,69	48,35	27,55	47,82	2,05
23	25,5	9,73	17,32	25,86	7,72	15,96	1,60	25,90	7,75	16,07	1,51
24	35,52	26,71	26,01	35,96	23,77	28,12	0,84	35,94	24,31	28,40	1,30
25	43,32	8,31	32,85	42,79	2,20	32,05	1,46	42,87	2,30	31,93	1,38
26	39,47	42,54	30,09	40,36	50,78	39,66	5,41	40,49	51,04	39,63	5,65
27	47,46	20,61	24,89	47,98	16,46	26,79	1,64	47,99	16,64	26,88	1,58
28	67,01	13,65	34,47	68,44	8,92	37,58	2,29	68,36	8,83	37,57	2,20